

The practice of crime linkage

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RESEARCH ARTICLE

The practice of crime linkage: A review of the literature

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Abstract

Crime linkage has been the subject of increasing attention in academic research. Research has found support for the principles of behavioural consistency and distinctiveness, which underpin crime linkage, but this does not provide direct evidence as to whether crime linkage is useful *in practice*. This literature review draws together documentation that refers to the practice of crime linkage, from assessing analysts' efficacy, to discussing the usage of computerised tools to assist with the linkage process, to providing a comprehensive outline of the process itself. The implications of the amount and type of information currently available are discussed, including the variations in practice and terminology that were explored. Avenues for future investigation and the manner in which future research could be conducted are set out in a research agenda.

KEYWORDS

behavioural consistency, behavioural distinctiveness, comparative case analysis, crime linkage, linkage analysis, signature analysis

1 | INTRODUCTION

Crime linkage is the process of linking two or more crimes together on the basis of the crime scene behaviour exhibited by an offender (Woodhams, Hollin, & Bull, 2007). With regard to academic research of this topic, the theory of crime linkage has received an increasing amount of attention in the last decade. This research largely focuses on testing the two fundamental assumptions of crime linkage: behavioural consistency and behavioural distinctiveness (Bennell & Canter, 2002). An offender's behaviour must be similar enough that it can be recognised across a series of offences and distinctive enough that it can be distinguished from other offenders' behaviour (Woodhams & Bennell, 2014), in order for crime linkage to work effectively.

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Crime linkage is currently used to inform police investigations of a range of crime types, in cases of sexual assault and murder (see the Serious Crime Analysis Section; National Crime Agency, n.d.) and in a wider variety of crime types according to police service priority, notably burglary, robbery, and car crime (Burrell & Bull, 2011). In some countries, it is also used to support prosecutions in court (Labuschagne, 2006, 2012; Pakkanen, Santtila, & Bosco, 2014). Using offender behaviour to link crimes can be advantageous where more traditional linkage methods are expensive and time-consuming (Pakkanen, Zappalà, Grönroos, & Santtila, 2012), or where there is limited or no physical forensic evidence (Grubin, Kelly, & Brunsdon, 2001; Labuschagne, 2014).

Theoretical research has reflected the broad application of crime linkage, finding support for the principles of behavioural consistency and distinctiveness in burglary (Bennell & Canter, 2002; Markson, Woodhams, & Bond, 2010), personal and commercial robbery (Burrell, Bull, & Bond, 2012; Woodhams & Toye, 2007), sexual assault (Harbers, Deslauriers-Varin, Beauregard, & van der Kemp, 2012; Santtila, Junkkila, & Sandnabba, 2005; Woodhams & Labuschagne, 2012), car theft (Davies, Tonkin, Bull, & Bond, 2012; Tonkin, Grant, & Bond, 2008), arson (Santtila, Fritzon, & Tamelander, 2004), and homicide (Salfati & Bateman, 2005; Santtila et al., 2008). Support for these principles has also been found using samples containing several crime types (Tonkin & Woodhams, 2017), both unsolved and solved offences (Woodhams & Labuschagne, 2012), one-off and a series of offences (Tonkin, Santtila, & Bull, 2012), and using different methodologies and data from different countries (Ellingwood, Mugford, Bennell, Melnyk, & Fritzon, 2013; Tonkin et al., 2017). Although these empirical studies have found support for the theories of behavioural consistency and distinctiveness, this is often caveated with the notion that these theories do not hold for all offenders, and within all series, to the same extent (Woodhams & Labuschagne, 2012). Further observations have been made that certain behaviours appear more (statistically) successful at linking crime series together than others. For example, in studies of the principles underpinning crime linkage (rather than its practice), geographical and temporal information results in statistical predictions of linkage that are more accurate (Tonkin, Woodhams, Bull, Bond, & Palmer, 2011), as have behaviours over which offenders are thought to be able to exercise greater control and which are less susceptible to situational influence (Grubin et al., 2001).

These findings from the academic literature have obvious implications for the practice of crime linkage; support for the principles of crime linkage can give credence to the practice of crime linkage in general, and certain research may be able to generate hypotheses about particular behaviours that would be more useful to crime analysts during the crime linkage process than others. Indeed, importantly, not finding support for these principles would suggest that such a practice would be ineffective, so the influence of these positive results cannot be understated. What this research does not do, however, is assess how these results translate to the *practice* of crime linkage. As noted above, crime linkage can be used in both an investigative context and a legal context. In terms of using crime linkage in a legal context, standards of admissibility exist in some countries that need to be satisfied before crime linkage has the potential to be used as evidence in those countries' courts. The practice of crime linkage, for example, needs to have been subject to peer review and publication and be generally accepted in the appropriate scientific community (see relevant court cases where these issues have been discussed; e.g., *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 1993; *Her Majesty's Advocate v. Thomas Ross Young*, 2013; *State of New Jersey v. Fortin*, 2000). These issues, though, pertain more to the subsequent use of crime linkage evidence after it has been conducted, rather than the practice of linking itself. Crime linkage as used in an evidentiary context, therefore, is not the subject of this review; rather, its focus is on crime linkage conducted in an investigative context.

When used as an investigative tool, the potential ramifications of inefficient or erroneous crime linkage could be severe. This consideration is especially important given that crime linkage is used in this capacity across many different policing contexts and across different continents, including countries in Europe (Rainbow, 2014), North America (Hazelwood & Warren, 2004), and Africa (Labuschagne, 2006). Inaccurate linkage predictions may hinder, rather than help, an investigation, including the inappropriate allocation of law enforcement resources and, in the case of incorrectly identifying several cases as linked, generating unwarranted media interest and unnecessary public anxiety (Grubin et al., 2001). With these considerations in mind, academic research needs to focus, not just on the theoretical underpinnings of crime linkage but also on the practice of crime linkage itself. Despite what are pressing research

considerations in this area and the use of crime linkage across the world, there has not, to date, been a review of the literature on the practice of crime linkage. This article, therefore, aimed to draw this literature together.

2 | METHOD

The term “crime linkage” in this article was used as a blanket term for all types of behavioural crime linking, but it must be recognised that variations in the practice of crime linkage are distinguished through the use of distinct terminology in practical settings. In the United Kingdom, for example, a distinction has been made between comparative case analysis (CCA) and case linkage analysis (CLA; Rainbow, 2014). This distinction denotes searching through a database for crimes that share distinctive behavioural similarities (CCA), as opposed to offering an opinion as to whether a number of offences presented to an analyst as a possible series are, in fact, linked (CLA). The former tends to be conducted by Serious Crime Analysis Section, whereas the latter is conducted by the United Kingdom's behavioural investigative advisers (BIAs). Woodhams, Bull, and Hollin (2007) also made the distinction between reactive CCA (searching for potential links to cases on a database of offences using an index offence/series as a reference point) and proactive CCA (searching for potential links between offences without starting with an index offence/series). For the sake of clarity, any reference to CCA in this paper refers to reactive CCA unless otherwise specified.

These differences must be borne in mind when considering the practice of crime linkage, and, as such, all terminologies used in research and practice were incorporated into the search process. The academic literature discussed in this article was searched using PsycINFO (from 1806 to February 2018) and Westlaw UK (searches run on 5 March 2018; cases and legislation excluded). The following keywords were used in separate searches in order to find relevant, peer-reviewed material written in English (in several instances, multiple keywords were combined in the same search as indicated below, and due to the volume of Westlaw UK search results, these queries were further refined using more stringent combinations of keywords): “crime analyst”; “crime linkage”; “case linkage”; “crime” & “case analysis”; “crime” & “linking”; “crime” & “linkage analysis”; “comparative case analysis”; “behavio(u)ral investigative advice.”

Searches were also conducted using Google Scholar, and reference lists of pertinent documents were searched for any further relevant material. Any document was considered relevant if it pertained to behavioural crime linkage (using behaviour demonstrated at a crime scene in order to make inferences about whether or not two or more crimes may have been committed by the same offender) *and* if it referenced the practice of crime linkage (as opposed to evaluating the theoretical underpinnings of crime linkage). Any literature reviews pertaining to the practice of crime linkage were also included. Differences in terminology are returned to in Section 3.

All articles were assessed for relevance; only publications where the practice of crime linkage was the main focus were included in this review. The following sorts of documents were not included in the review: the use of crime linkage in court, such as studies of the reception of crime linkage evidence by juries (e.g., Charron & Woodhams, 2010; Fawcett & Clark, 2015); investigations of the justification of claims made about links by practitioners (Almond, Alison, & Porter, 2007); and descriptions of how the assumptions of crime linkage might be considered by an analyst when conducting linkage and how these assumptions would need to be considered in terms of the benefits and risks of crime linkage (Alison, Goodwill, & Alison, 2005). The reliability of linkage is also questioned in some literature including, as noted above, its lack of acceptability as legal evidence given its failure to meet the Daubert criteria for admissible expert evidence (Ormerod & Sturman, 2005), but as noted above, this was not considered the primary purpose of this review. Many of these references to the practice of crime linkage are secondary considerations in research concerned with the theoretical principles, as opposed to being considerations in their own right. Where the practice of crime linkage was mentioned in passing or as part of another discussion, articles were excluded. This necessitated exclusion of many practitioner documents found (such as the *Practice Advice on Core Investigative Doctrine*, the *Guidance on Major Incident Room Standardised Administrative Procedures*, and the *Murder Investigation*

Manual; Association of Chief Police Officers [ACPO], 2005a, 2005b, 2006, respectively), whose focus, although mentioning the utility of crime linkage in passing, was not exclusively that of linking crimes. Finally, one study was considered for inclusion because of its investigation into whether one of the linking methods used by practitioners is effective (Schlesinger, Kassen, Mesa, & Pinizzotto, 2010) but was excluded on the basis that it examined the theory of consistency in ritual behaviours, as opposed to whether these behaviours are operationally useful.

The search process, including the inclusion and exclusion criteria and the number of results returned at each stage, can be seen in Figure 1. At the end of this process, 30 documents remained, all of which were reviewed (see Table 1 for details of these papers).

3 | RESULTS

In comparison with the volume of literature investigating the theoretical principles of crime linkage, the number of documents focusing on the practice of crime linkage is much smaller. These articles have been summarised and are

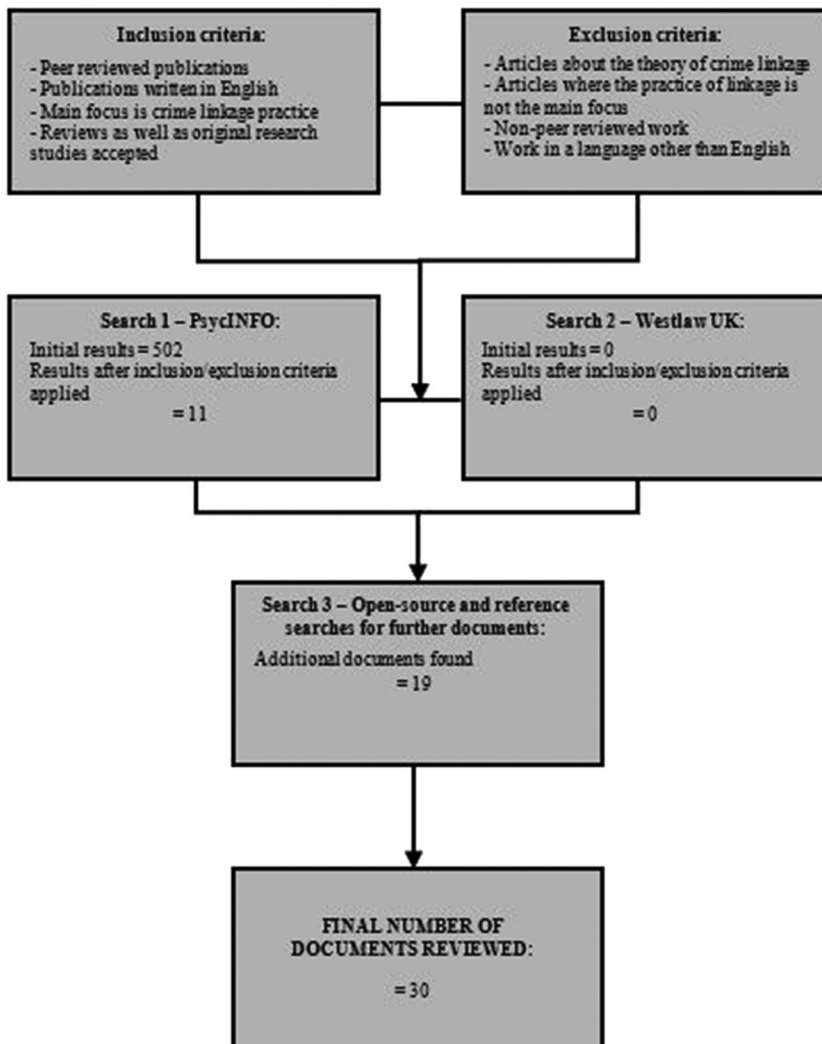


FIGURE 1 The search process

TABLE 1 Details of the documents included in the review

Author(s) and publication date	Publication name	Country of origin	Location of publication
Bennell, Bloomfield, Snook, Taylor, and Barnes (2010)	Linkage analysis in cases of serial burglary: Comparing the performance of university students, police professionals, and a logistic regression model	Canada	Journal article in <i>Psychology, Crime & Law</i>
Bennell et al. (2012)	Computerised crime linkage systems: A critical review and research agenda	Canada	Journal article in <i>Criminal Justice and Behavior</i>
Burrell and Bull (2011)	A preliminary examination of crime analysts' views and experiences of comparative case analysis	United Kingdom	Journal article in <i>International Journal of Police Science & Management</i>
Canter et al. (1991)	A facet approach to offender profiling	United Kingdom	Report produced by the offender profiling research unit: Surrey University
Cole and Brown (2012)	When is it best to seek assistance from a behavioural investigative adviser?	United Kingdom	Journal article in <i>The Journal of Homicide and Major Incident Investigation</i>
Craik and Patrick (1994)	Linking serial offences	United Kingdom	Journal article in <i>Policing</i>
Davies, Imre, and Woodhams (2019)	A test of the interrater reliability of the Violent Crime Linkage Analysis System (ViCLAS) coding in Belgium	United Kingdom	Submitted for publication
Douglas and Douglas (2006)	Modus operandi and the signature aspects of violent crime	United States	Book chapter in the <i>Crime Classification Manual: A Standard System for Investigating and Classifying Violent Crimes</i>
Douglas and Munn (1992)	Violent crime scene analysis: <i>Modus operandi</i> , signature, and staging	United States	Journal article in <i>Law Enforcement Bulletin</i>
Hazelwood and Warren (2004)	Linkage analysis: Modus operandi, ritual, and signature in serial sexual crime	United States	Journal article in <i>Aggression and Violent Behavior</i>
Keppel (1995)	Signature murders: A report of several related cases	United States	Journal article in <i>Journal of Forensic Sciences</i>
Keppel (2000a)	Investigation of the serial offender: Linking cases through <i>modus operandi</i> and signature	United States	Book chapter in <i>Serial Offenders: Current Thought, Recent Findings</i>

(Continues)

TABLE 1 (Continued)

Author(s) and publication date	Publication name	Country of origin	Location of publication
Keppel (2000b)	Signature murders: A report of the 1984 Cranbrook, British Columbia cases	United States	Journal article in <i>Journal of Forensic Sciences</i>
Keppel and Birnes (2008)	Serial violence: Analysis is modus operandi and signature characteristics of killers	United States	Book
Keppel et al. (2005)	The Jack the Ripper murders: A modus operandi and signature analysis of the 1888–1891 Whitechapel murders	United States	Journal article in <i>Journal of Investigative Psychology and Offender Profiling</i>
Labuschagne (2006)	The use of a linkage analysis on the conviction of the Newcastle serial murderer, South Africa	South Africa	Journal article in <i>Journal of Investigative Psychology and Offender Profiling</i>
Labuschagne (2012)	The use of a linkage analysis as an investigative tool and evidential material in serial offences	South Africa	Book chapter in <i>Serial Offenders: Theory and Practice</i>
Labuschagne (2014)	The use of linkage analysis evidence in serial offence trials	South Africa	Book chapter in <i>Crime Linkage: Theory, Research, and Practice</i>
Martineau and Corey (2008)	Investigating the reliability of the Violent Crime Linkage Analysis System (ViCLAS) crime report	Canada	Journal article in <i>Journal of Police and Criminal Psychology</i>
Mugford and Martineau (2014)	The ability of human judges to link crimes using behavioural information: Current knowledge and unresolved issues	Canada	Book chapter in <i>Crime Linkage: Theory, Research, and Practice</i>
Pakkanen et al. (2012)	The effects of coding bias on estimates of behavioural similarity in crime linking research of homicides	Finland	Journal article in <i>Journal of Investigative Psychology and Offender Profiling</i>
Rainbow (2014)	A practitioner's perspective: Theory, practice, and research	United Kingdom	Book chapter in <i>Crime Linkage: Theory, research, and practice</i>
Rainbow and Gregory (2009)	Behavioural investigative advice: A contemporary view	United Kingdom	Journal article in <i>The Journal of Homicide and Major Incident Investigation</i>
Rainbow et al. (2014)	Behavioural investigative advice	United Kingdom	Entry in <i>Encyclopedia of Criminology and Criminal Justice</i>

(Continues)

TABLE 1 (Continued)

Author(s) and publication date	Publication name	Country of origin	Location of publication
Santtila, Korpela, and Häkkinen (2004)	Expertise and decision making in the linking of car crime series	Finland	Journal article in <i>Psychology, Crime & Law</i>
Snook et al. (2012)	The Violent Crime Linkage Analysis System: A test of interrater reliability	Canada	Journal article in <i>Criminal Justice and Behavior</i>
Tonkin (2012)	Behavioural case linkage: Students, crime analysts, and statistics	United Kingdom	Chapter in unpublished doctoral dissertation: <i>Behavioural Case Linkage: Generalisability, Ecological Validity, and Methodology</i>
Turvey and Freeman (2011)	Case linkage: Offender modus operandi and signature	United States	Book chapter in <i>Criminal Profiling: An Introduction to Behavioral Evidence Analysis</i>
Woodhams, Bull, and Hollin (2007)	Case linkage: Identifying crimes committed by the same offender	United Kingdom	Book chapter in <i>Criminal Profiling: International Theory, Research, and Practice</i>
Yokota et al. (2017)	Practice of offender profiling in Japan	Japan	Journal article in <i>International Journal of Police Science & Management</i>

presented in Table 2. Section 3 has been organised according to the following four broad themes represented in the documents in the review: (a) the process of crime linkage; (b) the accuracy of decision making and factors affecting accuracy; (c) the use of computerised databases in crime linkage; and (d) suggestions for research based on practitioners' experience.

From the literature reviewed, it is clear that there is not one universal approach or methodology followed when conducting crime linkage. As noted above, rather than "crime linkage" representing one process, it is an umbrella term under which a number of different approaches to the practice are subsumed. Within each approach, however, there also seems to be a number of different methodologies used to link crimes. For the sake of clarity, this review has made the explicit distinction between "approach" and "methodology." Here, the word approach has been used to describe the context in which links are searched for: using a database to search for potential links versus assessing the likelihood of series membership within a prescribed group of offences, for instance. In this way, CCA and CLA are different *approaches* to conducting crime linkage. The methodology used to conduct crime linkage can also differ; searching for links on the basis of similarity at the individual behavioural level or at the level of themes of behaviour, for example, are different *methods* for identifying links between crimes, but both of these *methodologies* could be adopted by practitioners of either *approach*.

3.1 | The process of crime linkage

Most of the sources identified from the systematic search that were concerned with explaining the process of crime linkage are focused on CLA (as opposed to other approaches to crime linkage). As noted above, CLA is concerned with obtaining an expert's opinion as to the likelihood of a set of crimes (or some crimes within the set) being a linked series, where the police already suspect that they may have been committed by the same offender. The methods of conducting CLA, however, do differ and are described using a number of different terms: "signature analysis" (Keppel, 2000a; Keppel & Birnes, 2008); "linkage analysis" (Hazelwood & Warren, 2004); "dimensional behavioural linking"; and "multivariate behavioural linking" (Winter et al., 2013). There is less information on the methodologies used when conducting CCA, although some information about this crime linkage approach is detailed in the literature. It is worth noting that many of the publications reviewed here are written by practitioners or ex-practitioners (e.g., Hazelwood & Warren, 2004; Rainbow, 2014).

The earliest research on this topic comes from the United States and relates to the Federal Bureau of Investigation's method of conducting CLA. Keppel (2000a), for example, explored the history of the investigative use of *modus operandi* (MO) in the context of linking crimes, the use of what they deem to be an offender's MO and signature behaviour, and crucially, the conducting of what is termed a "signature analysis" in order to assess whether crimes ought to be considered linked. It is posited that an offender's MO is "the way a particular criminal operates" (Keppel, 2000a, p. 124) and consists of behaviours that are subject to change due to an offender learning and subsequently adapting their behaviour. The signature (sometimes called the trademark; Keppel, 1995), on the other hand, is a collection of behaviours that (a) demonstrates the offender's "personal expression" (Keppel, 2000a, p. 125); (b) constitutes a number of unnecessary behaviours that go beyond the criminal act itself; (c) may incorporate the unusual; and (d) is indicative of an attempt on the part of the offender to satisfy inner fantasies. Furthermore, although the signature may evolve, it is generally consistent; "The ritual may evolve, but the theme persists" (Keppel, 2000a, p. 132). It is this signature that is used in order to conduct a signature analysis; the crimes suggested to be linked are assessed in order to consider whether they contain the same "signature," the same set of behaviours indicative of an offender's inner desires. Keppel (1995, 2000a) has described a number of case studies in order to demonstrate the identification of a signature during CLA, including one in Canada (Keppel, 2000b), looking for the same underlying theme while also accounting for an offender's escalation, which could result in the evolution of the specific signature behaviours.

The next methodology to be described in the U.S. literature by the Federal Bureau of Investigation is termed "linkage analysis" (Hazelwood & Warren, 2004). As in Keppel's work, Hazelwood and Warren (2004) explained that

TABLE 2 A summary of the documents reviewed

Author(s)	Study aims	Methodology and sample	Main findings
Bennell et al. (2010)	Comparing a logistical model, university students, and police professionals (half of which received training) in their ability to link burglaries accurately, including whether training increases accuracy.	Forty students and 31 police professionals were given 38 details of pairs of commercial burglaries and were asked to assess which pairs were linked. Trained participants were given information on how to make these decisions. A logistic regression model was applied to the 38 pairs.	Both the untrained students and police professionals groups performed significantly better than chance. The students, contrary to expectations, outperformed the police professionals. All of the trained participants outperformed the untrained participants, and the statistical model performed significantly better than all of the human participants.
Bennell et al. (2012)	Reviewing the literature available pertaining to computerised systems designed to assist with the process of crime linkage.	Relevant literature was critically reviewed with reference to four areas of discussion: reliable coding of data; accuracy of data used; validity of the principles of behavioural consistency and distinctiveness; and accuracy of those using these systems.	Two articles pertaining to the coding of VICLAS are discussed. No research was found concerning the accuracy of data used. A number of articles are referenced to discuss the notion of behavioural consistency and distinctiveness, as well as factors that might affect these principles. Three articles that discuss the accuracy of linkage decisions are referenced, although it was noted that none of these studies included participants with particular training in behaviourally linking crimes. A future research agenda for each area of investigation is also discussed.
Burrell and Bull (2011)	Understanding the experiences and views of analysts conducting CCA in police services in the United Kingdom.	Qualitative analyses were conducted on the transcripts of 18 analysts' survey responses. The analysts came from both urban and rural police service in the United Kingdom and were asked questions about why and how CCA is conducted, the information used, as well as the challenges and benefits.	CCA was conducted on a number of different offences, including rape, murder, burglary, and robbery. CCA was typically conducted by searching for all relevant information, including temporal, spatial, forensic, and behavioural data, before creating a matrix of factors designed to easily demonstrate similarities across cases. Why some offences were considered easier to link than others was discussed, as well as the potential for CCA to assist with investigations in a number of ways. Lack of quality data, minimising false positives and negatives, and linking different

(Continues)

TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Canter et al. (1991)	Investigating the accuracy of human judges when conducting a linkage task.	Thirty-two U.K. detectives were given information on 12 solved sexual assaults (four series each containing three offences). Participants were asked to make linkage decisions about the cases, both individually and as part of a group.	offence types were all highlighted as challenges to the process. In terms of linkage accuracy, there were substantial differences between participants' performances. The largest proportion of participants when conducting linkage individually was correct in 25% of cases. There was some indication that participants were able to identify useful factors to link crimes, although using this information in MSA plots yielded better linkage results than did those made in the group discussions.
Cole and Brown (2012)	Exploring the best time for SIOs to request BIA assistance.	Eleven SIOs were interviewed regarding their experience of using BIAs. The interview transcripts were content analysed.	The optimum time in an investigation to call a BIA was discussed, with some SIOs suggesting this should not be at the very initial stage of enquiry due to a lack of information, although others disagreed. The different input BIAs could have at each stage was also discussed. The article suggests how SIOs could make the best use of the expertise of a BIA, including giving clear guidelines of what is needed from the BIA, and what the intended use would be of advice received.
Craik and Patrick (1994)	Reviewing how behavioural information can be used to assess links between offences.	A case study was used to demonstrate how matrices of behaviour can be created, to look for links between offences.	The benefits of using matrices to look for links between offences are discussed, including how information can be more easily assessed when directly compared in this manner. The benefits of behaviourally linking crimes during the course of an investigation or investigations are also discussed.
Davies et al. (2019)	Investigating the level of interrater reliability of coding demonstrated by analysts working in Belgium's centralised ViCLAS unit.	Eight analysts coded four rape cases into ViCLAS. The POA and PNOA were calculated for each section, case, and overall, as well as the number of variables in each section reaching 70% and	The mean POA score across all four cases was 55.80%, with scores ranging from 51.60% in case 3 to 64.80% in case 1. In terms of consistency, 13.13% of the variables' POA scores reached the

(Continues)

TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Douglas and Douglas (2006)	Discussing the merits of using the signature analysis to look for links between offences.	80% acceptability thresholds. These results were compared with previous research's results. Consistency of reliable coding was also assessed across the four cases.	70% acceptability threshold across all four cases. The mean PNOA score across all four cases was 88.99%, with scores ranging from 87.02% in case 2 to 92.25% in case 1. In terms of consistency, 74.10% of the variables' PNOA scores reached the acceptability threshold across all four cases. Both the POA and PNOA scores were almost universally higher than in previous research, although many sections did not reach the 70% acceptability threshold.
Douglas and Munn (1992)	Explaining the utility of using MO behaviours and an offender's signature to link crimes in the United States.	Several examples and case studies were outlined to explore the concepts of MO and signature behaviour. Case study examples were used to explore the utility of using different behaviours to conduct linkage, and the concept of crime scene staging.	The merits of and differences between an offender's MO and signature behaviour are discussed. The case studies are used to illustrate, in particular, the significance of identifying an offender's signature. The difference between the MO behaviours and the behaviours that form an offender's signature is outlined. Two case studies are also outlined that explore the utility of identifying and using both the MO and the signature to link crimes together. The notion of crime scene staging is also discussed, and a further case study has been used to illustrate this concept.
Hazelwood and Warren (2004)	Explaining the process of linkage analysis in the United States.	The concepts of the MO, ritualistic, and signature aspects of sex offences were explained, and a case study was used to illustrate these points.	The case study is outlined, followed by the step-by-step process of conducting linkage analysis. Notably, in this case study, the analyst was not allowed to testify as to whether they believed the cases were linked but rather allowed to suggest how similar the offences were, and that a similar signature existed in each of them.
Keppel (1995)	Explaining the process of conducting a signature analysis in the United States.	A case study was used to identify how signature analysis can be conducted on a series of murders.	The difference between the MO and the signature is explored. At the request of a deputy

(Continues)

TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Keppel (2000a)	As above, explaining the process of conducting a signature analysis in the United States.	As above, a case study was used to highlight how signature analysis can be used to link a series of murders.	prosecutor, the author conducted a signature analysis on three murders, which are documented here, concluding that one suspect was responsible. This was subsequently corroborated by forensic evidence.
Keppel (2000b)	Explaining the process of conducting a signature analysis in Canada.	As above, a case study was used to demonstrate how signature analysis can be used to link two murders.	The difference between the MO and the signature is explained here, as well as the importance of considering an offender's signature. A case study containing two murders is outlined to demonstrate how a signature analysis can be conducted, ultimately leading to the conclusion that the two cases were committed by the same offender.
Keppel and Birnes (2008)	Exploring in depth the MO and signature aspects of offender behaviour.	A book dedicated to exploring the MO and signature, with reference to several case studies to illustrate the concept.	The article outlines the first instance of a signature analysis being conducted for entry as evidence in a Canadian court. (Ultimately, DNA evidence was presented, which rendered the signature analysis unnecessary.)
Keppel et al. (2005)	Using signature analysis to assess potential links between the Whitechapel murders.	Information about the 11 relevant crimes was gathered, and their MO and signature characteristics were compared. Frequencies of these characteristics were also searched for on HITS.	The notions of MO and signature are defined and are then explored through the use of case studies. These case studies are used to highlight particular aspects of offender behaviour, e.g., piquerism, in order to demonstrate how they relate to an offender's MO and signature. (There is some duplication in this book of case studies found in other articles reviewed here.)
			The rarity of the similar signature characteristics in six of the 11 crimes is noted, taking into account potential offender escalation and the impact of interruptions. These similar details led the authors to conclude that these six offences were the work of the same killer (Jack the Ripper).

(Continues)

TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Labuschagne (2006)	Explaining how the process of linkage analysis is conducted in South Africa.	A case study was presented to illustrate how crime linkage, specifically linkage analysis in this case, was conducted.	The process of linkage analysis is outlined, using a case study to demonstrate each step, including consideration of several aspects of the manner and circumstances of the crimes. The article outlines how the court went on to accept the linkage analysis testimony and the subsequent sentencing of the offender.
Labuschagne (2012)	As above, explaining how the process of linkage analysis is conducted in South Africa.	A review of the current relevant literature was undertaken, and two case studies were presented to demonstrate how crime linkage is conducted.	What linkage analysis is and why it is useful is discussed, as well as the theoretical literature that exists that supports the principles of crime linkage. The information needed to complete a linkage analysis and the factors that can influence its completion are outlined, as are the legal considerations of its admission into the courts. Two different case studies are presented that give a more detailed and individual indication of the steps taken in South African linkage analysis.
Labuschagne (2014)	As above, explaining how the process of linkage analysis is conducted in South Africa.	As above, a review of the current relevant literature was undertaken, and two case studies were presented to demonstrate how crime linkage is conducted.	The uses of linkage analysis are discussed, including when caution should be used when attempting to link cases together, such as considering behaviours in isolation as opposed to considering the context in which they are exhibited. Two further case studies are also outlined in this article to further detail the process of linkage analysis in South Africa.
Martineau and Corey (2008)	Investigating the level of interrater reliability demonstrated by police officers when coding two fictitious cases into ViCLAS.	One hundred sixteen police officers coded a homicide scenario, and 121 coded a sexual assault scenario into ViCLAS. The overall percentage agreement, as well as the POA and PNOA, was calculated for each section and overall in each case. The impact of training was also considered.	The level of interrater reliability between participants, when looking at the percentage agreement results, was relatively high at 87.70% (sexual assault scenario) and 79.30% (murder scenario). The POA and PNOA scores, however, showed a lower level of interrater reliability (POA: sexual assault scenario = 25.38%; murder scenario = 38.43%; PNOA: sexual assault

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TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Mugford and Martineau (2014)	Reviewing the available literature concerning the accuracy of crime linkage decisions.	All of the studies pertaining to the accuracy with which humans conduct crime linkage were reviewed.	<p>scenario = 68.80%; murder scenario = 54.67%). No significant difference was found in interrater reliability results between those participants with ViCLAS training and those without ViCLAS training.</p> <p>Four studies are identified that explore how accurately humans conduct crime linkage. The limitations of these studies are explored, specifically the type of stimuli used, which type of linkage task is used to test accuracy, how experience is defined, the manner in which decisions are made by participants, and the fact that actuarial models are considered the best alternative to human judges of linkage, as opposed to taking into account the benefit of using experience to make such decisions.</p>
Pakkanen et al. (2012)	Testing whether prior knowledge of linkage status (linked or unlinked) affected the similarity of behaviour coded by participants.	Three groups, each containing 20 Italian university students, were asked to code 10 Italian serial murder cases (five series each containing two offences). The first group was correctly told about linkage status, the second incorrectly informed, and the third given no information. Participants were then asked to binary code the information in each case, and correlations were calculated to assess any differences between groups.	Contrary to expectations, the correctly informed group, in comparison with the incorrectly informed and the uninformed groups, did not code significantly more similarity in the cases. Further, no significant difference in perceived similarity was found between any of the three groups. Some small, statistically insignificant results were found: the correctly informed group coded slightly more similarity than did the incorrectly informed group, and the uninformed group coded more similarity than did the correctly and incorrectly informed groups.
Rainbow (2014)	Reviewing the considerations of conducting CLA in the United Kingdom.	A review of the information concerning CLA was undertaken, with the use of a case study to illustrate the approach.	CLA is considered within the context of behavioural investigative advice, and both the theoretical and methodological considerations of this approach are discussed. How CLA is conducted is also outlined using extracts from a U.K. case study.

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TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Rainbow and Gregory (2009)	Explaining the modern view of behavioural science within the context of the investigation of major crime.	Information pertaining to behavioural investigative advice in the United Kingdom was outlined.	<p>Considering where in the investigative process CLA is used is also discussed; namely, its use exclusively at the investigative stage. A proposal to conduct CLA in a more empirical framework is also suggested.</p> <p>How behavioural investigative advice can be used during the investigative process is discussed, including generating hypotheses from assessing the crime scene and giving investigative suggestions, conducting CLA and offender profiling, generating potential suspect names and prioritisation matrices, conducting risk assessments and familial DNA prioritisation, and giving media and interview advice. It also discusses the limitations of behavioural investigative advice, the information a BIA requires, and how to use advice received from a BIA.</p>
Rainbow et al. (2014)	Summarising what behavioural investigative advice is and its context within the investigative process.	A summary entry in the <i>Encyclopedia of Criminology and Criminal Justice</i> .	<p>Behavioural investigative advice is placed in its criminal context, and where it lies in comparison with international perspectives in this area. The different aspects of behavioural investigative advice are outlined, including generating hypotheses, assessing the crime scene, and making investigative suggestions, conducting CLA and offender profiling, generating and prioritising suspects and prioritising familial DNA, and giving interview, search, and media-related advice. The process of how the BIAs create and compile their advice is also outlined.</p>
Santtila, Korpela, and	Investigating whether experience in investigating car crime was related to the accuracy of linking these types of series.	Two sets of 15 cases (in total, 10 series containing three offences each) were given to four groups of 33 participants; experienced car crime	<p>The naïve participants were significantly less accurate at linking cases than all of the other groups. There were no other significant</p>

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TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Häkkinen (2004)		investigators; experienced investigators (not of car crime); novice participants (with 6 months investigative experience or less); and naïve participants (with no experience of investigating crime). Participants were asked to link crime series, thinking aloud as they made their decisions, and then rate their performance in and the difficulty of each series. Semistructured interviews were also conducted with participants to better understand their decision-making processes.	differences between groups, although the experienced car crime investigators' mean was the highest, followed by the other experienced investigators, and then the novices. The groups did not significantly differ in the time they took to complete the tasks, and there was no correlation between individual predictions about performance and actual accuracy. The features used to link crimes differed between groups, with the experienced car crime investigators mentioning less features used to conduct linkage overall. When links were based on the factors "vehicle type," "time of theft," or "taken without permission," they were more likely to be linked, and incorrect links were based more often on the factors "extent of property stolen" and "type of property stolen."
Snook et al. (2012)	Investigating the level of interrater reliability of police officers' ViCLAS coding in Canada.	Ten police officers were asked to code a real case into ViCLAS (nine of whom had previously coded information into ViCLAS). The POA was calculated, as well as the number of variables meeting an 80% acceptability threshold.	An overall POA score of 30.77% was found, ranging from 2.36% (weapon section) to 62.87% (administration section). In terms of the number of variables reaching the 80% acceptable threshold, 10.38% of all variables achieved this level of agreement.
Tonkin (2012)	Investigating the performance of both trained and untrained students and crime analysts in comparison with a statistical linking model.	One hundred students and 37 crime analysts were split into two groups and asked to identify the links in either 15 burglary or 15 robbery offences (each including three linked and 12 unlinked pairs). Linkage accuracy using a statistical model was also assessed in both cases.	In the residential burglary condition, the regression models outperformed both groups. In the robbery condition, the crime analysts were significantly more accurate than both the regression model and the student group. In terms of effects of training, training in the burglary condition increased student accuracy but decreased crime analyst accuracy. Trained participants also increased their use of the intercrime distance in their linking.

(Continues)

TABLE 2 (Continued)

Author(s)	Study aims	Methodology and sample	Main findings
Turvey and Freeman (2011)	Explaining the process of linkage analysis.	The premise of linkage analysis (or case linkage as it is also referred to here) was outlined, with reference to an offender's MO and signature.	The differences between the MO and signature are explored, including their significance to linking offences. Specific elements of the MO are outlined, as are significant aspects of the signature, such as repetition.
Woodhams, Bull, and Hollin (2007)	Reviewing the information on the process of crime linkage.	A review of the available information concerning crime linkage was conducted, with particular reference to U.K. practice.	The purpose of crime linkage is outlined, followed by the process of conducting crime linkage, specifically CCA. The theory of crime linkage is also explored, as well as the research available that evaluates the principles underpinning crime linkage. One article is identified that pertains to the practice of crime linkage. Further, issues with linking crimes are also addressed, including data limitations, issues with geography, and the obstacles associated with its acceptance in court.
Yokota et al. (2017)	Investigating the use of offender profiling in Japan, as well as assessing the accuracy of the crime linkage and profiling conducted.	Two hundred ninety-six solved offences were examined to assess whether and how profiling and crime linkage were used. (A survey of 156 people responsible for conducting profiling was also carried out, to obtain demographic details of these participants and understand their profiling related experience.)	In terms of crime linkage, four different methods were identified as being used to conduct CLA (one of which pertained to comparing visual information including offender description, as opposed to using offender behaviour). Some type of crime linkage was conducted in 76% (n = 210) of the 280 serial offences.

Abbreviations: BIA, behavioural investigative adviser; CCA, comparative case analysis; CLA, case linkage analysis; HTS, Homicide Investigation Tracking System; MO, *modus operandi*; MSA, multidimensional scalogram analysis; PNOA, percentage nonoccurrence agreement; POA, percentage occurrence agreement; SIO, senior investigating officer; VICLAS, Violent Crime Linkage Analysis System.

MO behaviours are the behaviours necessary to commit the crime and noted that learning, confidence, and situation can all change an offender's MO, although they do suggest that successful MO behaviours are likely to remain consistent. Hazelwood and Warren also introduced the concept of ritualistic behaviours, which, similar to the concept of Keppel's signature behaviours, denote the internal psychology of an offender, born of their motivation and sexual fantasy. These behaviours are deemed to be symbolic and highly individual to the offender and, contrary to what has been previously suggested, are said to be subject to change via escalation, which occurs through an offender refining the acting out of fantasies, or through the addition of new behaviours that the offender unexpectedly found to be satisfying (e.g., sexually arousing) in prior offences. Importantly for this method of conducting CLA, Hazelwood and Warren explained that the signature is a unique combination of both MO *and* ritualistic behaviours, rather than only ritualistic behaviours. In the search for a signature, they outline a number of observations; it is likely more MO than ritual behaviours will be observable; a ritual may not always be present in all crimes across a series; ritual behaviours may be mistaken for MO behaviours; some behaviour may be both MO and ritual; it may not be possible to recognise ritual behaviours; and, if the crime is impulsive, a ritual may not exist at all. In order to assess whether a signature exists, a number of steps are outlined that are designed to assess how likely it is that a series of offences have been committed by the same offender. First, as much information as possible about the crimes is gathered, followed by a review of all of the information to identify the significant features of each crime. These features are classified as either MO or ritual, before being compared across the series in order to determine whether a signature exists. Finally, a report of the process is written detailing the conclusions of the analysis. Hazelwood and Warren also used a case study to illustrate how such linkage analysis is conducted. They further note the importance of recognising any dissimilar features between cases to assess whether they can be explained on the basis of the context of the crimes. They acknowledge there may be features within cases that may not be easily identifiable as either ritual or MO; for instance, the disposal location of a body may result from the offender deliberately placing it there, or the victim running from the offender to said location; equally, a behaviour may function as both an MO and a ritual behaviour.

As in the articles already outlined, Douglas and Munn (1992) also stressed the importance of both the MO and signature for crime linkage. They also make the important point that an offender's MO may be subject to change, not just because of offender learning but also because of the effect a victim's reaction may have on the offender's subsequent actions. MO may also be subject to change due to destabilising factors affecting the offender, such as increased alcohol use (Turvey & Freeman, 2011). Douglas and Munn, as in Keppel's work, suggested that the signature never changes but instead evolves, although as in Hazelwood and Warren's (2004) article, they posited that it may not always be present due to interruptions or other external influences. Douglas and Douglas (2006) gave examples of how linkage analysis may apply to serial murder, serial rape, arson, and terrorist offences. (Keppel predominately writes about murder and sex offences.) One further consideration made by Douglas and Munn is the notion of staging, that either an offender or those close to the victim may alter the crime scene, either for the purposes of misleading the investigation or to give the victim dignity in death. In either event, these authors caution that any staging can act as a confound when attempting to link offender behaviour.

A similar methodology to that outlined in the U.S. literature—also termed “linkage analysis”—is used in South Africa, as explained by Labuschagne (2012), the then Head of the Investigative Psychology Unit of the South African Police Service and a clinical psychologist. Labuschagne described the steps of linkage analysis as starting with those outlined in Hazelwood and Warren's (2004) article and added that geographical behaviour should be considered (i.e., considering the geographical proximity of crime scenes). Labuschagne proposed that the benefit of using this linkage analysis, as opposed to a signature analysis, is that it is not reliant on the presence of unnecessary behaviours and can be conducted using MO behaviours. This means, as Labuschagne pointed out, that it has the advantage of being able to link crimes on the basis of unusual or unique combinations of MO behaviours. Again, Labuschagne used a number of case studies in order to demonstrate the method of linkage analysis, looking at both the manner and the circumstances of the crimes, in order to determine the signature observable across the offences (Labuschagne, 2006, 2012, 2014).

CLA has also been written about by the BIAs working in the United Kingdom. Some of these publications discuss in broad terms the role of the BIAs, highlighting that it is part their remit to provide advice as to whether cases may be linked or not (Rainbow & Gregory, 2009; which is reproduced in Rainbow, Almond, & Alison, 2011; the 2009 article has been reviewed here) and that the data held in the Violent Crime Linkage Analysis System (ViCLAS; a computer database used for the collation of information used to link violent crimes; Collins, Johnson, Choy, Davidson, & MacKay, 1998) can be used to guide a BIA's decision making or to produce statistics to demonstrate to the investigative team the rarity of individual behaviours or combinations of behaviours (Cole & Brown, 2012; Rainbow, Gregory, & Alison, 2014). Other articles from the United Kingdom's BIAs address the process of CLA in more detail; Rainbow (2014), for example, identified two specific methods used during the U.K. CLA process. The first is "dimensional behavioural linking," assessing whether several of the behaviours exhibited are demonstrative of an underlying theme, in order to assess consistency of this theme, rather than the specific behaviours themselves. The second is "multivariate behavioural linkage," using databases of behaviours to establish the commonality of one or more specific behaviours in combination, and thus their utility in linking crimes. Similar database usage has been highlighted by Keppel (2000b), noting that searches can be run on the Homicide Investigation Tracking System (a Washington database of sexual assaults and murders) to determine behaviour frequency. Godwin (2000) also highlighted similar decision support systems designed to help police with the linkage process, often based on ANACAPA; "a tabulation process whereby all information considered relevant to an inquiry can be collated in chart form" (p. 183). Finally, Craik and Patrick (1994)—two detective superintendents within the Metropolitan Police Service in the United Kingdom—discussed, in the absence of computerised databases, the benefits of creating matrices to better visualise similar behaviour across offences and more easily suggest whether they are linked.

Most recently, Yokota et al. (2017) have described how CLA is conducted in Japan. They identified 280 investigated cases (primarily sexual assaults, thefts, robberies, and arsons); in 210 of these cases, crime linkage had been used. Yokota et al. described four methods of crime linkage used in these cases. First, in 84% of cases, behavioural case analysis was conducted, linking crimes on the basis of offence characteristics. Second, visual information including offender description was used in 68% of cases. Third, 5% of cases were linked using distinctive behaviour across the crime series; and fourth, 4% of links were made on the basis of multi-dimensional scaling or cluster analysis of offence characteristics. It is important to note that the manner in which crime linkage is conducted in Japan is not explicitly outlined, although mention of the consistency and distinctiveness of offence characteristics suggests the approach is equivalent to what has been outlined here as CLA. Further publications that provide more detail about the different linking methods outlined in this work (such as what constitutes "offence characteristics") would benefit the field. Because of these omissions, it is currently difficult to ascertain the exact differences between each method; it is not clear, for example, the difference between methods 1 and 4, other than the use of statistics in method 4. Further, although "visual information" is something analysts may consider during the linkage process, by themselves they do not constitute offender behaviour.

In terms of CCA, there is much less information about the methodologies used. Burrell and Bull (2011) conducted a survey of 18 crime analysts working in two U.K. police services in order to gain an insight into their experiences of the practice of CCA. A 23-question survey was developed using the first author's practical experience of working with crime analysts, and the theoretical literature available at the time. This study was useful in that it addressed specific considerations in the linking process—questions of why and how CCA is conducted—as well as particular evidence for and benefits and challenges to CCA. Interestingly, during the interviews, participants did distinguish between proactive and reactive CCA, although the effect on the linkage process of conducting one instead of the other was not detailed. CCA was conducted by either identifying all of the offences that a known offender has committed or identifying different series within a particular offence type. Analysts stated that CCA was conducted on a range of offences, including rape, murder, burglary, robbery, and car crime, although it was noted that they did not tend to specialise in conducting CCA on a single crime

type. Analysts said CCA took from as little as 20 to 30 min to as long as several weeks to complete. The typical process was described as first retrieving data from relevant police databases and then constructing a matrix of factors used to link crimes in order to assess similarity visually across offences. A range of behavioural, temporal, and spatial factors were used to link offences, including the use of a weapon, time and day of the week, and offence location. The potential unreliability of information was highlighted as an issue with regard to conducting linkage, for instance, offender ethnicity being unreliable because of the precautions offenders took to obscure their faces. Analysts also noted data quality in general as a barrier to conducting efficient CCA: having to source additional information because of missing data, for instance, making the process of CCA longer. Once links were suggested, they were assessed as to their strengths and weaknesses, with some analysts suggesting they would be inclined to include both strong and tentative links in their reports to officers (provided they were highlighted as such).

Woodhams, Bull, and Hollin (2007) documented the steps of reactive CCA, on the basis of the first author's experience of working as a crime analyst in the United Kingdom, and provided a valuable guide as to what could be considered a general, "standard" approach to conducting CCA. First, all of the available documentation is requested and read, before constructing a list of behaviours shown in the index offence/series (as above, the index offence/series is the term given to the crime[s] to which links may subsequently be made). Analysts then search for crimes with similar behaviour, constructing lists of behaviours for other potentially similar offences. Once this has been done, they then consider (a) the similarities and dissimilarities between the index offence/series and (b) the rarity of any similar behaviours, thereby weighting them. Finally, a report is written for the police or Crown Prosecution Service, detailing the analyst's findings (Woodhams, Bull, & Hollin, 2007).

3.2 | The process of crime linkage—section summary

From looking at this research, it is clear that, although the approach to conducting crime linkage may remain broadly the same, the method used to conduct crime linkage can vary widely. The benefit of much of this literature is that it is written by current or ex-practitioners of CLA and CCA. The CLA literature includes case studies of conducting signature analysis using publicly available information about infamous cases, such as Jack the Ripper (Keppel, Weis, Brown, & Welch, 2005), or on cases on which the author worked first hand (Labuschagne, 2012). The benefit of using case studies is that the author is able to provide a great deal of detail about how crime linkage was conducted in that particular instance. The downside is that because of idiosyncrasies within any one case (or particular experience one practitioner brought to that case), the method used to link crimes in one instance may not be applicable to others. In contrast, in the CCA literature, generalised methods are described in one article. Although this means the specific behaviours with which offences are considered potentially linked are absent from the article, the benefit of considering a standardised method of conducting CCA means the effects that any idiosyncrasies may have on the linkage process are eliminated. Detailing the standardised method to linkage also circumvents the notion that the case studies have been chosen as examples of conducting linkage precisely because (a) they are particularly receptive to the practice of crime linkage or (b) they were particularly unusual or difficult to solve. The consequence of the former point is that these cases are not likely to display any common difficulties normally encountered during the linkage process. The consequence of the latter is that, although it would explain why practitioners were asked to consult on the cases, it would also mean the manner in which these cases are treated are likely to be different to how other, more typical cases would be subject to the linkage process. In either event, some of the potential issues that relying on case studies may cause are demonstrated here. A combination of both techniques—for example, a general description followed by a case study—may be a way of best describing the different linkage processes. What is also important to highlight here is that most articles are written using examples of specific crimes types, and there is currently no research that looks at whether the process of linking crimes for one crime type may be effectively transferred to linking crimes of other types.

3.3 | Accuracy of decision making and factors affecting accuracy

The accuracy of crime linkage decisions is a topic that has been subject to previous review (Mugford & Martineau, 2014), in particular looking at human efficacy of conducting crime linkage, the effect of experience on this practice, and the manner in which linking decisions are made. Previous research has used a number of different participant groups, including law enforcement personnel, lay-people, and even mathematical models, to investigate crime linkage accuracy. In terms of the accuracy of law enforcement personnel, Canter et al. (1991) investigated the accuracy of 32 U.K. police detectives' linkage decisions regarding a series of sexual assaults. Most of the officers performed at a chance level of accuracy, although there was a significant between-participant variation in linkage accuracy. Performance below chance level was attributed to the difficulty with choosing aspects of behaviour relevant to the linkage task, and considering and combining the amount of information available in order to assess whether cases are linked (Canter et al., 1991). More recently, Yokota et al. (2017) investigated the number of times 156 police professionals used crime linkage, and in how many of the instances the decisions made were correct or not. Links were incorrectly made in 15% of cases, on the basis of participants making links to crimes committed by another offender, and in 52% of cases, potential links had failed to be confirmed. The authors themselves recognised that it was likely many of these were unconfirmed, not because of the inaccuracy of the link, but simply because of the difficulty of confirming some links without other evidence (such as DNA or offender confession).

Although it is important to understand the decisions made by law enforcement personnel as to what increases accuracy, it is equally important to understand whether decisions that increase accuracy are attributable to the expertise of the participant. In other words, the question is whether law enforcement personnel, in comparison with lay-people, should be more accurate, on the basis of their general experience of crime, crime series, and potential training received. Studies testing this notion have typically compared law enforcement groups with experience of conducting crime linkage with non-law enforcement groups with no such experience, or compared different law enforcement groups with varying degrees of linkage expertise. Santtila, Korpela, and Häkkinen (2004) investigated whether greater linking accuracy would be demonstrated by experienced car crime investigators compared with experienced investigators of other crime types, inexperienced investigators, and "naïve" participants (or lay-people). They also recorded the type of information participants used in order to make their linkage decisions, and they assessed whether this information was actually useful in linking crimes in terms of being associated with greater accuracy. Thirty-three participants were asked to complete a linking task pertaining to several car thefts during which they articulated their thought process to the researchers. They were also subsequently interviewed to describe the linkage process. In terms of performance, the naïve participants performed significantly worse than all other groups, and although there was no significant difference between the different types of investigators, the mean linkage accuracy was highest in the experienced car crime investigators group.

In order to further assess the notion of expertise as an influence on crime linkage accuracy, studies have also introduced an element of training to certain participant groups in order to test whether this training (designed to introduce an element of expertise) affects linkage accuracy. Bennell et al. (2010) investigated whether differences existed in linkage accuracy of burglary offences between groups of students, police professionals, and a computerised statistical model of linkage, with half of all participants receiving training. Perhaps surprisingly, all of the untrained participants performed significantly better than chance; however, there were differences between the different participant groups. The students significantly outperformed the police professionals, and the participants who received training outperformed those who did not. The students placed greater emphasis in their decision making on geographical information about the crimes, and there was a strong trend that trained participants also placed greater reliance on the same information.

More recently, Tonkin (2012) recruited 37 crime analysts with specific experience of crime linkage and 100 students and asked them to link a number of crimes. Participants were randomly assigned to groups linking either residential burglaries or commercial robberies, and to groups receiving either training similar to that in previous research (Bennell et al., 2010) or no training. With regard to the commercial robbery condition, the analysts performed

significantly better than did the students. For the residential burglary condition, however, there was no significant effect of training or experience on performance. Instead, training was associated with increased accuracy by the students but decreased accuracy by the analysts. When looking at the information used by participants, the analysts relied more on the map provided, and those with training relied more on intercrime distance. Some of these results contradict previous research, and it seems as though participants were able to identify more effective strategies for linking in Tonkin's study. This may be explained by the fact that participants had more relevant experience of conducting linkage, and specifically of conducting linkage with the crime type used in the study, than had participants in previous research.

As mentioned above, comparisons have been made between the accuracy of humans and computerised statistical models. Bennell et al. (2010) found that their statistical model significantly outperformed all human participants in terms of linkage accuracy. Conversely, Tonkin (2012) found that the analysts outperformed the regression models in the commercial robbery condition, and that there was no significant difference in accuracy between the regression models and the student sample. The regression models outperformed both the students and the analysts in the residential burglary condition. The variation between the analysts' performance in the robbery conditions compared with the statistical models may, however, simply be an artefact of the small number of linkage decisions made, and the large drop in percentage accuracy that one mistake would have generated (Tonkin, 2012).

Finally, accuracy could be measured as a function of the different methodologies used to link crimes (as outlined above). Unfortunately, no studies currently exist that aim to test whether any of the different methodologies used to conduct linkage produce more accurate results.

As well as assessing the overall accuracy of linkage decisions made, the efficacy of particular parts of the linkage process can also be assessed. Pakkanen et al.'s (2012) study investigated whether prior knowledge of links between cases would create a bias as to the similarity perceived in an offender's behaviour across a series, when participants coded the information in each case as present, absent, or missing. This is an important research question for the CLA scenario where the police have already put forward an opinion as to whether they consider a group of crimes to be linked before the analyst and then conducts their analyses. It also has ramifications for the population of computerised databases designed to assist analysts with the linkage process. Participants were assigned to three groups, one with information about links between cases prior to coding, one that had been misinformed about links prior to coding, and one that was given no information. Although the incorrectly informed group coded less similarity for their linked cases than did both the correctly informed group and the uninformed group, this trend was nonsignificant, and the uninformed group coded the most similarity (although, again, the difference between this group and the correctly informed group was nonsignificant). As such, no clear evidence was found for the presence of a coding bias. (Interestingly, the analysts interviewed in Burrell & Bull's, 2011, study mentioned the notion of bias, their awareness of it, and their desire to remain objective. This may play a part in counteracting the effects of bias, although this notion needs empirical testing.)

3.4 | Accuracy of decision making and factors affecting accuracy—section summary

The research in this section has shown that there can be large variation in individual performance when conducting crime linkage, and one possible explanation for this may be the types of behaviours that participants focus on when conducting crime linkage. Santtila, Korpela, and Häkkinen (2004) demonstrated that experienced car crime investigators relied on fewer variables when making their linkage decisions, with results showing that correct linkage decisions were made when considering vehicle type, time, location, or chains of thefts. Participants who performed better more often mentioned the time of the theft, whereas the type and extent of property stolen were often the bases for errors in linkage decision making. It is worthy of note that the variables resulting in more accurate linkage are those that are under the offender's control, in contrast with those that are more situation dependent (Woodhams, 2008), and reflective of results found in the theoretical literature. In Bennell et al.'s (2010) study, potentially useful information, such as the temporal information of the crime, was not given to the participants,

information that more experienced police professionals would rely on, many of whom noted its absence. This indicates that the types of behaviours used to link crimes are important, and that their absence from a research paradigm may affect a study's findings.

A major limitation of each of these studies is that none of them state which crime linkage approach they are attempting to study. Furthermore, all of the tasks in these studies are much simplified in comparison with the real-life process as undertaken by practitioners. For example, Pakkanen et al. (2012) used edited summaries of murder case transcripts, which would not be reflective of the many case papers generated in a murder investigation. As a consequence, the results of such studies will have limited applicability to real-world practice. For example, a computerised statistical model may function well when completing a simple crime linkage task but may be much less effective when having to consider the complexities of a real case as outlined in many of the case studies explored above. Such studies need repeating under conditions of greater ecological validity. That students outperformed police professionals (Bennell et al., 2010) may be because the task differed considerably from what the police professionals' normal linkage tasks entail, thus limiting their ability to apply their expertise to the task. As noted above, and as recognised by the authors, the police professionals were not given information that they would normally use when attempting to conduct crime linkage, and furthermore, nine of the 31 police professionals were police officers who may have had little or no previous experience of linking crimes (Bennell et al., 2010). Conversely, although the students in this study had no experience of policing or linking crimes, there was no mention of their familiarity with behavioural psychology, which may have accounted for a certain level of expertise. Furthermore, training consisted only of the information that previous research had indicated that geographical proximity was an effective indicator of linkage; it is possible that students were more likely to take this sort of training on board, whereas the police professionals may have placed greater weight on their own operational experience, essentially disregarding the training. Tonkin (2012) addressed some of these issues; participants, for instance, were asked for their specific experience of conducting crime linkage, two of the three computerised models were based on data geographically different to those of the crimes in the questionnaire, and participants were presented with temporal as well as geographical and behavioural information. Some limitations of previous research still stand, however, in that the context of the task was artificially generated and may not reflect the way that crime linkage is conducted in practice. In this way, there is no guarantee that these studies provide a valid picture of the levels of accuracy achieved in practice, or the factors that may affect accuracy. Although there has been an attempt to investigate which behaviours are important in linkage, the exact processes used and the order in which decisions were made by analysts have not been outlined (Santtila, Korpela, & Häkkinen, 2004), and efficacy of different decision-making frameworks has not been compared, which makes it difficult to attribute potential efficacy to any one decision.

3.5 | The use of computerised databases in crime linkage

Interacting with computerised databases can be an integral part of a practitioner's role when conducting crime linkage (Burrell & Bull, 2011). Indeed, although no comprehensive review of the practice of crime linkage has been conducted to date, a critical review and research agenda concerning such computerised databases do exist, highlighting a number of key factors that need to be addressed in order to assess the utility of such databases (Bennell, Snook, MacDonald, House, & Taylor, 2012). Four key areas for attention were identified. The first stage is to establish whether the information held in such databases is reliable, which, Bennell et al. (2012) argued, should primarily be tested by ensuring a high level of interrater reliability of information coded by different analysts. Second, they posit that the data entered into these databases need to be accurate, and third, the principles of consistency and distinctiveness need to hold true. Last, Bennell et al. argued that practitioners should be able to accurately conduct linkage using the data held in these databases.

Whether the information entered into such computerised systems is reliable is something that has been considered by a number of articles. Martineau and Corey (2008) tested the interrater reliability of ViCLAS coding in

Canada. Although, at first glance, the results seemed positive, with participants demonstrating interrater reliability of 79.30% when coding a homicide scenario and 87.70% in a sexual assault scenario, when looking at the more stringent measures of percentage occurrence agreement (POA; the percentage of times raters agree information is present) and percentage nonoccurrence agreement (PNOA; the percentage of times raters agree information is absent), the results were less encouraging, with an overall POA of 38.43% and 25.38% and an overall PNOA of 54.67% and 68.80%, respectively. Snook, Luther, House, Bennell, and Taylor (2012) replicated Martineau and Corey's study, making notable changes to the methodology used. Instead of using mock cases, real case details were given to participants to code into ViCLAS. In this instance, only the POA was calculated, with a similarly low result of 30.77% agreement found overall. Snook et al. suggested a number of reasons as to why interrater reliability was so low: (a) that participants may have found the study's task boring or unimportant; (b) that participants were unfamiliar with the case materials; (c) that participants may have little experience of coding information into ViCLAS; (d) that the questions in ViCLAS themselves may be difficult to answer; and (e) that the case material was both complex and lengthy. Finally, Davies et al. (2019) conducted a similar study, using participants from the Zeden Analyse Moeurs unit in the Belgian Federal Police. This study was designed to address a fundamental difference in the manner in which ViCLAS is coded internationally; in some countries, such as Canada, the ViCLAS variables are coded by the officers conducting the investigation, whereas in many European countries, including Belgium, this is done by crime analysts working within a centralised unit. The results in this study were more encouraging, with an overall POA of 55.80% and an overall PNOA of 88.99%. Although these results are far from perfect, Davies et al. highlighted that only the first part of the coding process is investigated in these studies, with the effect of quality control processes used to improve reliability yet to be studied. What the results from this most recent study may demonstrate, however, is that the coding of human behaviour into quantifiable and standardised responses is a complex and difficult process, which may be mediated somewhat by the introduction of analyst expertise and familiarity born of consistent usage of a computerised database such as ViCLAS.

3.6 | The use of computerised databases in crime linkage—section summary

ViCLAS is typically used to search for potential links to an index offence/series and as such, although not specified, all three studies of the interrater reliability of ViCLAS coding make implicit reference to the practice of CCA. As noted above, Keppel (2000a, 2000b) mentioned Homicide Investigation Tracking System, which is used in order to determine the frequency of signature behaviours, both individually and in combination, to assess their rarity when making linkage decisions. Similarly, Labuschagne (2012) made reference to the Violent Criminal Apprehension Program, another database that can be used to assist with crime linkage. (Notably, Violent Criminal Apprehension Program was evaluated in the process of creating ViCLAS, but they are two distinct systems. More information about this can be found on the Royal Canadian Mounted Police's website <http://www.rcmp-grc.gc.ca/en>). This demonstrates the reliance on computerised databases in the practice of CLA as well as CCA in some countries, highlighting the importance of evaluating these databases that are used to support crime linkage decision making.

3.7 | Suggestions for research based on practitioners' experiences

There is no current literature that explicitly highlights how or whether specific current theoretical crime linkage research is actually used in practice. The effectiveness of geographical data for linking volume crimes (e.g., burglary and vehicle crime) as demonstrated in theoretical crime linkage research, for example, would suggest that this sort of behavioural information ought to be prioritised in the practice of linking these types of crimes (Tonkin et al., 2008). Another study (Godwin, 2000) tested whether statistical processes usually used in theoretical papers to assess consistency and distinctiveness could be used to assist with the practice of crime

linkage, although the number of unknowns in this study makes this more of an illustrative example than a rigorous test of the potential for statistical processes to be used during the linkage process (and as such was not reviewed above).

The difficulty of translating research into practice has been highlighted by Bennell, Woodhams, and Mugford (2014), who explained that research findings may not be useful in investigative settings because (a) the samples used in research may not be representative of samples found in real-life settings and (b) the nature of the linking tasks used in theoretical research may be different to those within a real-world investigative setting. Indeed, although some theoretical research does note the differences in crime linkage approaches (e.g., Bennell, Mugford, Ellingwood, & Woodhams, 2014), these practical differences are not always considered, meaning it may not be a straightforward process to infer the utility of theoretical research to crime linkage practice.

One study that does go some way to answering this question is Labuschagne and Salfati's (2015) article, which provides a summary of current academic research that may be of use when conducting crime linkage. For example, they noted Horning, Salfati, and Labuschagne's (2015) research on consistency of approach type, which has implications as to whether this type of behaviour should be relied on during the linkage process. It hypothesises about the potential use of specific aspects of research in practice and, importantly, also suggests that practitioner case work can inform a research agenda for the future—giving examples of such research that needs to be conducted—in order to ensure the translational nature of future research from theory to practice. What it does not do, however, is demonstrate how or whether this research is of actual value to practice (indeed, most of the research highlighted post-dates the cases to which the paper refers).

Analysts have demonstrated that they are mindful of the available academic research relevant to their profession (Burrell & Bull, 2011). As with Labuschagne and Salfati's (2015) article, though, at this point, what is perhaps most useful with regard to this section are the suggestions for further academic research made by practitioners who conduct crime linkage. Rainbow (2014), for example, requested that more research investigates the decision thresholds at which crimes should be considered linked (the importance of this factor is also echoed by other authors; Alison et al., 2005). A low decision threshold, for example, may result in more hits and fewer misses but increases the likelihood of false alarms. On the other hand, a strict decision threshold would mean fewer false alarms but also fewer hits. Empirical research that can inform such decision making would, therefore, be useful. (Some academic research has calculated what the "optimal" threshold would be for considering offences linked using Youden's calculation; e.g., Davies et al., 2012; Tonkin et al., 2008). These have not been reviewed here, however, as they do not consider the real-world factors that would be associated with setting a linkage threshold, and they are not studies of the practice of crime linkage. Similarly, Rainbow called for research that would further the development of CLA as an evidence-based practice, especially given the legal contexts in which it could be used. Last, Rainbow made the more general observation that his 2014 chapter is the only source to provide a detailed account of the differences between practitioners' approaches (CLA versus CCA), and he suggested a change in academic focus to better incorporate the concerns of practitioners of CLA, including developing an understanding of these different approaches to linking and using the appropriate terminology.

4 | DISCUSSION

The aim of this review was to determine the extent of the available literature on the practice of crime linkage. Although no information was found that suggests specifically how current theoretical research is used in practice, the review identified writings on how CLA and CCA are conducted using a number of different methodologies. Research on practitioner linkage accuracy was also found, in respect both to comparisons with nonexperts and to statistical models. Research into how computerised tools affect the linkage process has also started to be conducted.

In addition to its intended aims, this review has also identified novel areas of research need and areas where clarification is required. These are discussed below.

4.1 | The variation in practice

The major difference between approaches—namely, CLA and CCA discussed in this review—is something that is recognised within the literature; but, as highlighted here, there is often variation in the methodology used to carry out each approach, something not often overtly recognised. CLA is (or has been) used in the United States and Canada and is currently used in South Africa and the United Kingdom. In CLA, links are searched for in many ways, from using behaviours considered to be of personal significance to the offender (signature analysis; Keppel, 2000a) to identifying common behaviours or sets of behaviours across crimes, independent of their perceived significance to the offender (multivariate behavioural linking; Winter et al., 2013). Although many different methods for conducting CLA are described in the literature, much less information exists on how CCA is conducted. In fact, CCA has only been mentioned in U.K. research on crime linkage practice, although the ViCLAS interrater reliability studies that exist suggest that CCA is also used in Canada and Belgium. Indeed, the Royal Canadian Mounted Police confirm ViCLAS's current usage in Canada, the United Kingdom, and Belgium, as well as France, Germany, the Czech Republic, Ireland, the Netherlands, Switzerland, and New Zealand (Wilson & Bruer, n.d.). This suggests an even wider use of CCA globally than is currently reflected in the literature, although the exact methods used to conduct CCA in these countries are not, to date, publicly available. Were such details made available to researchers, a formal and thorough comparison of different linkage approaches and methodologies could then be conducted. Given some of the issues raised with relying on ritual behaviours to link offences, for instance (Schlesinger et al., 2010), research into linkage efficacy based on process is urgently needed.

Another area associated with how crime linkage is conducted is the notion of cognitive bias. The idea that bias may exist in the coding of offences has been investigated in one study (Pakkanen et al., 2012), and in another, analysts mention their awareness of this issue (Burrell & Bull, 2011). Despite the potential for cognitive bias to influence the results of linkage, however, this area has also received very little academic attention. Several biases have been identified, which may affect linkage efficacy: the clustering illusion, the availability heuristic, the base rate fallacy, and the representativeness heuristic (Rainbow et al., 2011), as well as the notion of ampliative blindness, the concept by which crimes in the same jurisdiction fail to be linked (Godwin, 2000). Exploration of ampliative blindness and these cognitive biases, as well as investigating others that may exist, is a necessary part of understanding more about the factors that may affect the efficacy of behaviourally linking crimes.

4.2 | The variation in terminology

Crime linkage has been recognised here as a blanket term that may encompass a number of different processes, but the lack of specific terminology used to describe each process does make the comparison between different research problematic. Furthermore, one of the major issues with writings on the practice of crime linkage is that the same terminologies are used to describe different processes. For example, there are papers on "linkage analysis" written by practitioners in different countries, where the steps that are undertaken to search for links are, in places, notably different (Hazelwood & Warren, 2004; Labuschagne, 2006). Attempting to describe each process in general terms, away from the nuances of specific case studies, would help to clarify the process underlying each term. It may be that a natural degree of evolution in the practice can account for discrepancies in the meaning of each term, or alternatively, that cultural differences may impact how linkage is conducted. The addition of the use of geography in Labuschagne's (2012) linkage analysis method, for example, could be attributable to either of these factors. Because these issues have not yet been explored, it is difficult to be certain whether the approaches and methodologies described here are still reflective of practice around the world today.

4.3 | The behaviours used to conduct crime linkage

Although a number of studies describe the steps involved in conducting crime linkage, there is little information on precisely what behaviours are chosen when conducting this process. There are, however, some inferences that can be drawn from the literature reviewed. The signature approach focuses on unnecessary behaviours, those posited to be important to the offender in terms of fulfilling their fantasy. In contrast, academic research has found “style” behaviours to be relatively inconsistent at an aggregate level (Grubin et al., 2001; Woodhams, 2008), and only consistent in some offenders. Further, although it is possible for unnecessary behaviour to be present in all types of crime (e.g., a burglar eating food from the victim's fridge), examples given of these types of behaviour often pertain to sex offences and murder, and it is not clear how useful these behaviours would be when attempting to link other crime types. It is also unclear whether unnecessary behaviours are considered to aid the linking process due to their distinctiveness, or whether they are deemed to be useful because of assumed consistency due to their significance to the offender.

The identification of rare behaviours is something that is highlighted in the linkage analysis approach of Hazelwood and Warren (2004). As with the unnecessary behaviours, however, there is no specification of what behaviours (or combination of behaviours) are distinctive and thus useful for linking crimes (other than those in the case studies outlined, which cannot be generalised to other cases).

Studies of expertise in crime linkage also provide some suggestions as to what behaviours are focused upon during this task. The Santtila, Korpela, and Häkkinen (2004) study of linking car thefts found that experts focused on behaviours under the offender's control, such as the vehicle type, as well as time and location of the offence. In Bennell et al.'s (2010) study, participants with experience of crime linkage suggested that temporal information would have been used in the linkage task if that information had been available to them, and the importance of these types of behaviours was highlighted in interviews of CCA practitioners (Burrell & Bull, 2011). This information suggests that there are certain behaviours perceived to be more useful for linkage than others, presumably because they remain relatively consistent as they are less subject to situational variance. Much of the academic literature would support the notion that geographical, temporal, and MO behaviours under an offender's control are of potential use in linking crimes due to their relative consistency (Woodhams & Bennell, 2014).

4.4 | How behaviours are conceptualised in theory and practice

As well as the type of behaviours deemed useful to the process of crime linkage, there is the matter of how these behaviours are actually conceptualised. In theoretical research, consistency is most often considered in terms of whether linked pairs are significantly more consistent than unlinked pairs, measured by creating similarity coefficients between each pair, either for each behaviour or for domains of behaviours. (Domains are groups of behaviours that share the same function, e.g., control or precautionary behaviours; Tonkin et al., 2008; in this way, behaviours are represented more generally, although it is important to note this differs from grouping behaviours into themes.) When considering thematic consistency, academic research first categorises cases into different themes and then measures in discrete terms whether or not crimes in series demonstrate the same theme.

Practitioners' use of both themes of behaviour and taking note of individual distinctive behaviours suggests they may be conceptualising behaviours, not just at a number of levels, but considering these levels simultaneously, something which the academic literature (with two notable exceptions; Melnyk, Bennell, Gauthier, & Gauthier, 2011; and Woodhams, Grant, & Price, 2007) has yet to do. Further, in the academic literature, consistency is usually measured at an absolute level. By contrast, practitioners seem to accept behavioural variations and implicitly consider relative consistency (even if this is not formally measured), factoring in small changes due to escalation, for example (Keppel, 2000b), to allow for the consideration of consistency given the context of the situation. Context and its effect on the consistency of behaviour are rarely discussed in the academic literature (although there are a few notable

exceptions; e.g., Woodhams, Hollin, & Bull, 2008), despite the importance that practitioners place on this factor (Labuschagne, 2014). These issues warrant further investigation.

4.5 | Setting out a research agenda

This review and evidence synthesis has indicated several areas of research and scholarly need for academics to consider. What is also striking is the scarcity of information about the actual practice and process of crime linkage. Although there are case studies of CLA written by practitioner authors, there is a need for a more generalised mapping of the processes divorced from the nuances of particular cases. What differences there might be in practice between countries could be disentangled from any differences potentially being a function of the specific illustrative cases chosen. Although the CCA process has been mapped out in general terms in one publication (Woodhams, Bull, & Hollin, 2007), this publication is more than a decade old. Burrell and Bull (2011) have made important inroads in this area by interviewing analysts about their experiences of conducting CCA, but much more detailed (published) information is needed about analysts' decision-making processes, including exactly which behaviours analysts prioritise and why, how they operationalise these behaviours, how context and the situational influence of cases are taken into account, the chronology of their decision making, and how the threshold at which cases are considered linked is set.

With the publication of more studies that clearly outline the methods of conducting CLA and CCA, it will be easier for academics to design studies that test the accuracy of crime linkage decision making in an ecologically valid manner. The same is true of the investigation into the effects of using computerised databases to assist with the linkage process; the more that is known about the manner in which these programmes are used during linkage, the easier it will be to construct studies that test their contribution to the process. Although expertise has been touched upon in the research into the practice of crime linkage, there remain many human factors involved in the crime linkage process, such as stress and cognitive fatigue, which have yet to be investigated. Although the notion of cognitive bias has been touched upon in the literature, this area of research requires expansion and further exploration. The efficacy of crime linkage, including the reliability of the information used for linkage and the reliability with which it is coded, and the different approaches and methodologies used need to be addressed, as do the error rates of practitioners conducting crime linkage in its various forms.

This review has highlighted discrepancies between the manner in which crime linkage is researched and how it is conducted in practice. This disconnect has been noted already by both researchers and practitioners (Rainbow, 2014). The fact that practitioners are publishing in academic outlets (e.g., Labuschagne, 2014; Rainbow, 2014) and that researchers and practitioners are coproducing research (e.g., the Crime Linkage International Network; Tonkin et al., 2017; Woodhams & Labuschagne, 2012) suggests there is a desire from both parties to bridge this gap. Closer academic-practitioner working would facilitate crucial knowledge exchange, not only advancing the understanding of crime linkage practice, but also ensuring that research better meets practitioner need. This would also align with the increasing need to ensure policing is evidence based (Sherman, 2013). Although there are challenges associated with such collaboration, such as issues of sharing sensitive data, or differences in academic and practitioner priorities, these are not insurmountable problems. Researcher secondments into practitioner workplaces, practitioner-academic networks and groups, conferences that integrate the perspectives of both parties, and practitioner contributions to special journal issues and books are all useful ways to encourage collaborative working and a two-way dialogue.

4.6 | Limitations

The main limitation of this review is that an exhaustive list of all of the available information, in particular documents written by practitioners, which may not be publicly available, will not have been included here. Despite the effort to search for practitioner writings using open source searches, it is likely that much of this type of information will not

be in the public domain. Further, there will be documentation from other countries—written by both academics and practitioners—that will have also been omitted here. This factor again highlights the importance of cooperation between practitioners and academics from the international crime linkage community.

5 | CONCLUSION

The goal of this literature review was to identify and synthesise what is known about crime linkage practice. Although there is existing literature on the practice of crime linkage, this review highlighted the paucity of such information and the knowledge gaps that now need to be filled, including practitioner authored articles about the crime linkage process, as well as more ecologically valid academic studies. Given that crime linkage is widely used around the world, there is a sense of urgency with which this sort of research ought to be conducted.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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